

Variations in height of jugular "a" wave in relation to heart rate in normal subjects and in patients with atrial septal defect

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SUMMARY Analysis of jugular tracings in seven normal subjects in sinus rhythm whose heart rate varied spontaneously from one moment to another during expiratory apnoea, showed that a pronounced variation occurred in the size of the "a" waves in relation to that of the "v" waves and in accordance with the corresponding RR interval. In the 53 measurements which were carried out, the "a/v" ratio had a mean value of 0.9 for a heart rate above 87, 1.4 for a heart rate between 87 and 68, and 1.1 for a heart rate less than 68. The variations in the size of the "a" waves in relation to heart rate are explained by the place of atrial systole during the different phases of ventricular filling.

This variation in the height of the "a" wave has also been found in patients with an atrial septal defect for heart rates between 62 and 86, and this could lead to misdiagnosis, either dismissing the diagnosis of atrial septal defect when the heart rate is around these values, or suspecting it wrongly when the heart rate is either slower or faster.

When examining jugular tracings, one should therefore be cautious about interpreting the size of the "a" wave which should be evaluated as a function of heart rate.

Measurement of the height of the "a" wave, which reflects right atrial systole, is one of the features which is essential for study of the jugular venous pulse. It is considered in relation to the height of the "v" wave, and it is usual to regard the height of the normal "a" wave to be between one and one-and-a-half times that of the "v" wave.^{1,2} If it is above this value, one can presume an increase in pressure in the right atrium caused by an obstruction to the outflow. Below this limit it would suggest over-distension of the right atrium such as is seen, for example, in atrial septal defects.

In practice, the "a/v" ratio varies with the heart rate,³ a fact which has been appreciated only by few authors until now and the aim of the present study is to show, by observations on subjects with normal hearts, that the height of the "a" wave varies in relation to the heart rate and this notion finds an application in patients with an atrial septal defect.

Subjects and methods

NORMAL SUBJECTS

The reason for investigating these seven normal

subjects was the presence of a systolic murmur, the clinical features of which suggested that the heart was normal. These cases were selected because they were in sinus rhythm, with a heart rate which varied from one moment to another, even during a period of strict expiratory apnoea. The electrocardiogram was normal and sinus rhythm was confirmed by the constancy of the P waves, the PR intervals, and the ventricular complexes throughout the tracings, only the RR interval varying from one time to another.

All seven subjects were young, with a mean age of 21 (range: 15 to 35 years), three were female and four were male. The absence of an underlying cardiac lesion was first established on clinical, radiological, and electrocardiographic evidence, and confirmed in all cases by a complete phonomechanocardiographic study based on recordings of the phonocardiogram from different praecordial positions and of the jugular, carotid, and apical tracings. The carotid study was done at rest and repeated during a pharmacodynamic test with isoprenaline and with methoxamine. In one patient (case 4) haemodynamic and angiographic investigations were also carried out.

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If one regards the normal "a/v" ratio values to lie between 1 and 1.5, then 29 of the 53 measurements done were within normal limits (Fig. 3, shaded area) and there were 13 values below and 11 above these limits. The "a" wave values which fall within the accepted normal limits, that is between 1 and 1.5, could be seen at all heart rates. In the seven subjects studied, the RR interval ranged from 0.59 to 0.97 (heart rate of 102 to 62). For the 11 readings which were above 1.5, indicating abnormally large "a" waves, the RR intervals ranged from 0.69 to 0.88 s (heart rate of 87 to 68), except in one subject in whom the RR interval was 0.93. In the 13 cases in whom the "a/v" ratio was below 1, basically indicating small "a" waves, the RR intervals were either below 0.69 (heart rate above 87), or above 0.88 (heart rate below 68) except in three cases where the values were 0.70, 0.74, and 0.87.

One can therefore classify the "a" waves into three groups according to their height in relation to the RR intervals.

Type "1": The RR interval was below 0.69 (heart rate over 87). There were five "a" waves in this group which corresponded to an "a/v" ratio of less than 1 (and, therefore, unduly small) and three to a ratio of 1 to 1.5 (normal). The mean value of the "a/v" ratio for these five "a" waves was 0.9 (limits 0.6 to 1.2).

Type "2": The RR interval lay between 0.69 and 0.88 (heart rate between 87 and 68). There were 33 "a" waves in this group, 10 corresponding to an "a/v" ratio of more than 1.5 (therefore abnormally large), in 20 the ratio was between 1

and 1.5 (normal), and in only three was the ratio below 1 (abnormally small). The mean value of the 33 "a/v" ratios was 1.4 (limits 0.8 to 2.4).

Type "3": The RR interval was above 0.88 (heart rate below 68). There were 15 "a" waves in this group, of which eight corresponded to an "a/v" ratio of less than one (and therefore small), in six the ratio laid between 1 and 1.5 (normal), and in one case the ratio was above 1.5 (therefore large). The mean value of "a/v" was 1.1 (limits: 0.8 to 1.9).

In summary, the "a" waves regarded as normal in size, that is with an "a/v" ratio of between 1 and 1.5, occurred at all heart rates, the smaller waves ("a/v" ratio below 1) were only seen when the heart rate was either fast or slow, and the larger waves ("a/v" ratio above 1.5) only for the middle range of heart rates.

Two subjects merit detailed discussion.

Case 4 (Fig. 4) showed all three types and had a very variable heart rate from 97 to 61 (RR intervals of 0.62 to 0.99). Accordingly, the height of the "a" wave in this subject was very variable and represented all three types: 1, 2, and 3 according to whether the heart rate was fast, medium, or slow, with several intermediate values. This case showed in the same subject all the possible variations in the "a/v" ratio in relation to the heart rate, variations which were seen only incompletely in the other six subjects. In this subject one could recognise the division of the "a/v" ratios into three groups according to the values of the RR interval, one value of 0.6 for type 1, 18 (mean values 1.1) for type 2, and eight (mean value 0.8) for type 3. There was no overlap or separate divisions for the "a/v" values in relation to the RR intervals in the 27 "a/v" ratios measured, except for four values. For one RR interval of 0.87, two values differing slightly in their "a/v" ratio were equal to 0.9 to 1.1. For one RR interval at 0.70, the ratio was equal to 0.8, and for the fourth RR interval at 0.74, the ratio was 0.9.

The second patient was unusual for the pronounced variations in the size of the "a" waves in relation to relatively minor changes in the heart rate. Even when the RR interval went from 0.60 to 0.78, an increase of 30 per cent (heart rate from 100 to 77), the "a/v" ratio changed from 0.7 to 2.4, an increase of 240 per cent.

Comments

The facts given above contradict the accepted view that the size of the "a" wave is abnormal when, expressed as the "a/v" ratio, it is above 1.5 or below 1. In fact, the "a/v" ratio varies considerably with the heart rate as can be seen in the seven subjects recorded above in whom the heart rate

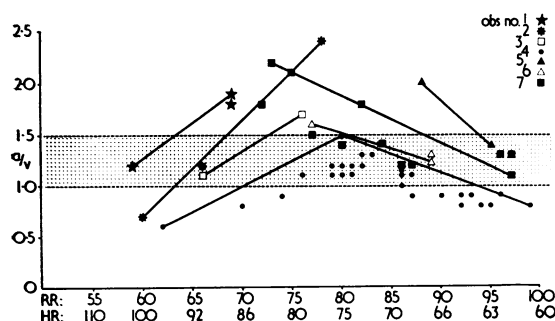


Fig. 3 Progression in the size of the "a" wave ("a/v" ratio) in relation to the corresponding RR interval in hundredths of a second, and to the heart rate (HR) in seven subjects. The end-points of this progression come together on the right-hand side. Note that in case 4 the pronounced variability in the RR interval allows the "a" wave to pass through the three different sizes. Shaded area is where the "a/v" ratio is usually regarded as normal.

changed spontaneously from one moment to another, though the electrocardiographic complexes remained exactly the same and the measurements were recorded during strict expiratory apnoea.

The "a/v" ratio had a mean value of 0.9 when the RR intervals were less than 0.69 and a mean value of 0.62, which corresponds to a rapid heart rate of more than 87 (mean 97).

The "a/v" interval is greater, with a value of 1.4, when the RR interval lies between 0.69 and 0.88 (mean 0.80) which corresponds to a heart rate between 87 and 68 (mean 75). Lastly, the "a/v" ratio is smaller (mean 1.1) when the RR interval is prolonged and above 0.88 (mean 0.94) which corresponds to a heart rate below 68 (mean 64). It should be noted that though there could be some overlap in the "a/v" values from one subject to another, there was none in the same subject (except slightly for two values in case 4). It should also be emphasised that the cut-off points for heart rate (fast: over 87; medium: between 68 and 87; slow: below 68), which have determined the classification of the "a" wave into three groups cannot be considered as strict values since we are dealing with only seven normal subjects.

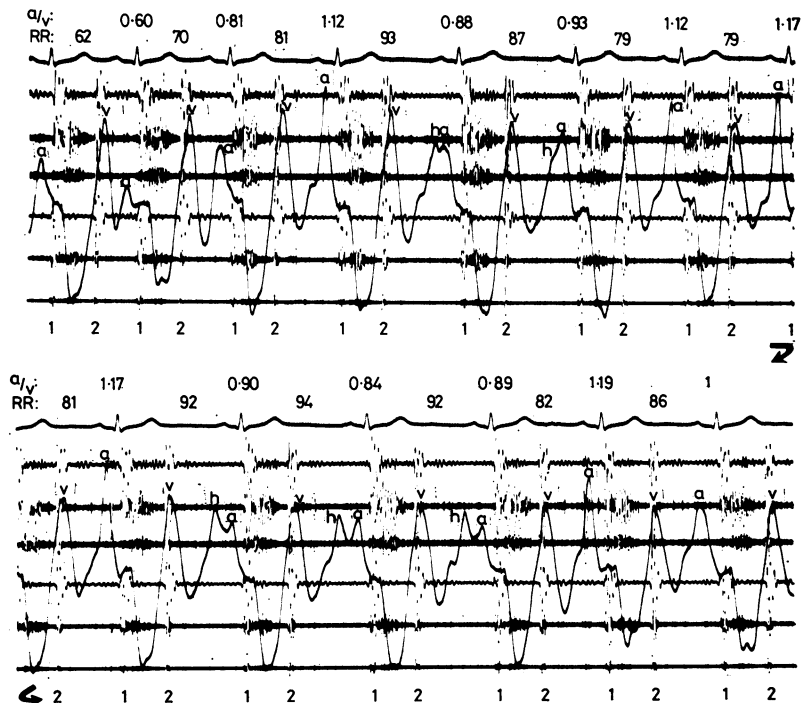
The size of the "a" wave in relation to the "v"

wave ought then to be interpreted with caution on jugular tracings as the "a/v" ratio can vary considerably with the duration of the RR interval, that is it follows the heart rate. The concept of a larger "a" wave should be interpreted with caution when the RR interval lies between 0.69 and 0.88 (heart rate 87 and 68), since an "a/v" ratio of more than 1.5 can be seen in normal subjects.

An "a/v" ratio of more than 1.5 does not necessarily represent an increased right atrial pressure if the heart rate lies between 68 and 87. In the same way, a small "a" wave, giving an "a/v" ratio of less than 1, should not necessarily suggest distension of the right atrium such as one sees in atrial septal defects, since an "a/v" ratio of less than 1 can be seen in normal subjects when the RR interval is below 0.69 (heart rate above 87) or above 0.88 (heart rate below 68).

The variations in the height of the "a" wave seem to depend mainly on the time when atrial systole takes place in relation to the different stages of ventricular filling (Fig. 5). When the heart rate is rapid (and the RR interval is short, below 0.69), atrial contraction takes place early, soon after the opening of the tricuspid valve, and the amount of blood discharged during atrial systole is to some

Fig. 4 Extract from a continuous jugular tracing in a normal subject (case 4) in expiratory apnoea. From above downwards: a standard electrocardiograph lead II, the first phonocardiogram at three frequencies (low, medium, and high) parasternally in the third left intercostal space, and, below, another phonocardiogram with the same frequencies at the apex area. "a/v", ratio of the size of the "a" wave in relation to that of the "v" wave; RR, RR intervals in hundredths of a second. Recording speed of the paper was 50 mm/s.



extent drawn by ventricular suction through the valve which is fully open. Atrial contraction cannot then cause an increase in atrial pressure. This explains why the "a" wave may be rather small on the jugular tracing and this takes place when the curve descends from "v" towards "y". When the heart rate is a little slower (RR interval between 0.69 to 0.88) atrial systole occurs during the rapid filling of the ventricle when the free borders of the valves are coming together. Atrial systole thus comes up against an obstacle on which it impacts and this causes a rise in the atrial pressure which shows itself as a larger "a" wave on the jugular tracing, and higher than the "v" wave. Finally, when the heart rate is slow (RR interval above 0.88) atrial systole occurs during slow ventricular filling and stasis, that is the phase when the valves have just opened and the ventricle can easily receive the contents of the atrium. Atrial contraction does not then lead to any appreciable rise in pressure and the "a" wave on the jugular tracing remains smaller than in the previous situation.

Variations in "a" wave size therefore respond to a physiological situation and this fact should be borne in mind when interpreting jugular tracings.

ATRIAL SEPTAL DEFECT

The diagnosis of atrial septal defect on the jugular pulse tracing is suggested when the "v" wave is higher than the "a" wave, which indicates an

increase in right atrial filling caused by left-to-right atrial shunt, whereas normally the "v" wave amplitude is less than that of the "a" wave.

Results

As in normal subjects, it seems that the amplitude of the "a" wave varies considerably with the heart rate and Fig. 6 shows a striking similarity to the curves seen in the previously studied normal subjects.

(a) In those with a rapid heart rate (RR interval below or equal to 0.70), the "a/v" ratio was usually below 1, and in no case was it above 1.5 (type 1 "a" waves).

(b) In those with a medium heart rate (RR interval between 0.71 and 0.96) the amplitude of the "a" wave was increased and the "a/v" ratio was generally above 1.5, and in all cases it was above 1 (type 2 "a" waves) except in two cases whose heart rate approached that of the following group.

(c) In those with a slow heart rate (RR interval above 0.96) the amplitude of the "a" waves was further diminished and the "a/v" ratio was below 1.5 or even below 1 (type 3 "a" waves).

The line of demarcation between the three zones is definite between the first two (RR=0.70), less clear-cut with a heart rate a little slower than in normal subjects between the last two (RR>0.96).

One interesting fact is that the "a/v" ratio is always above or equal to 1 for heart rates which

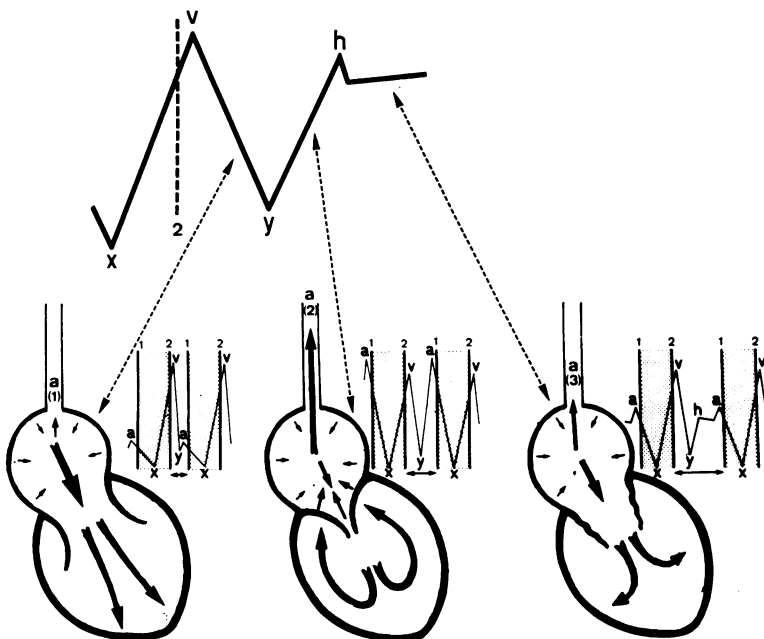


Fig. 5 Plan showing the three types of jugular tracing according to whether the "a" waves appear early or later during diastole. Above: the terminal point of a normal jugular vein tracing with the appearance of "x", "v", "y", and "h" and the second sound (2). Below: from left to right, the progressively later appearance of the "a" wave during diastole, either between "v" and "y" (=a1), or between "y" and "h" (=a2), or after "h" (=a3) (see text for comments).

would be considered as normal, above 60 and below 85. The presence of very large "a" waves (above or equal to two "v") can even be seen in this zone but they are very unusual in cases of atrial septal defect without pulmonary hypertension.

Among the four cases of atrial septal defect with a spontaneously variable heart rate, there were three (cases 1, 2, and 3) who presented with type 1 "a" waves smaller than the "v" waves, and changed to type 2 "a" waves, larger than the "v" waves,

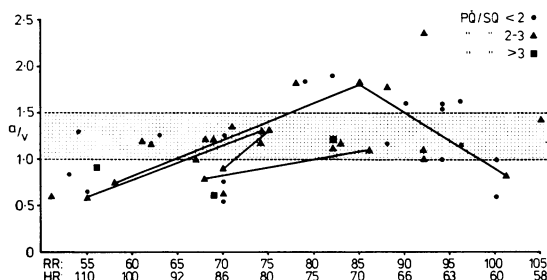


Fig. 6 The "a/v" ratio of the jugular tracings (on the ordinate) in relation to the RR interval in hundredths of a second or heart rate (HR) (on the abscissa). The shaded area is that inside which the "a/v" ratio can be considered as normal, the area below is that in which the "a/v" ratio is usually considered diagnostic of atrial septal defect. A line has been drawn joining the limits of the heart rates in four patients with atrial septal defect who had spontaneously variable heart rates. The points (pulmonary to systemic output ratio < 2), the triangles (ratio between 2 and 3 included), and the squares (output ratio > 3) refer to the 38 patients with a constant heart rate (see text for explanation).

when the heart rate fell below 85 ($RR > 0.70$), thus confirming the course of events noticed in the previous 38 cases. Fig. 7 is a striking example of this. The fourth patient (Fig. 6, case 4) had the advantage of showing the three possibilities together and summarising in one patient the general course of the "a/v" ratio in relation to the heart rate. This course of events recalls that seen in subjects at a fixed heart rate (Fig. 3) and that seen in normal subjects. Fig. 8 shows 87 "a/v" ratios which were taken during the same recording in this subject during a course of repeated expiratory apnoea.

Comments

As in normal subjects, the height of the "a" wave is related to the heart rate and the same general comments apply to patients with atrial septal defect. However, there are small differences regarding heart rates at which the variations in the height of the "a" wave occur.

The "a" wave becomes abnormally tall (type 2) for medium-range heart rates with an RR interval between 0.71 and 0.96 (instead of 0.69 and 0.88 for normal subjects).

It becomes smaller, either for fast heart rates (type 1) with an RR interval equal to or below 0.70 (instead of 0.69 for normal subjects) or for slow heart rates (type 3) with an RR interval above 0.96 (instead of 0.88 for normal subjects).

These small differences between normal subjects and those with atrial septal defect could in fact be the result of the relatively small number of normal subjects studied. However, the overall evolution of the height of the "a" wave in atrial septal defect

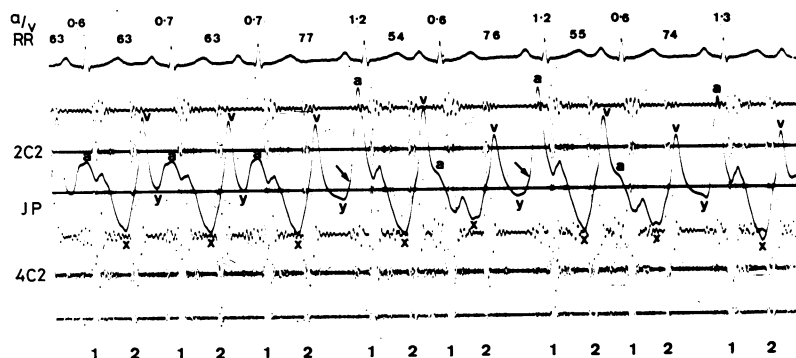


Fig. 7 Part of a jugular pulse and phonocardiogram tracing of a patient with atrial septal defect with a spontaneously variable heart rate. From above downwards: "a/v", ratio of the respective heights of the "a" and "v" waves; RR, RR interval in hundredths of a second; standard electrocardiograph lead II; the first part of a phonocardiogram recording with three frequency bands: low, medium, and high at the internal extremity of the second left intercostal interspace; the jugular pulse (JP) with the "a", "x", "v", and "y" waves. The arrows indicate the base of the "a" wave which is not clearly visible; a second phonocardiogram recording at the same frequencies as above, taken at the internal extremity of the fourth left intercostal interspace (1, 2: first and second heart sounds). See text for details.

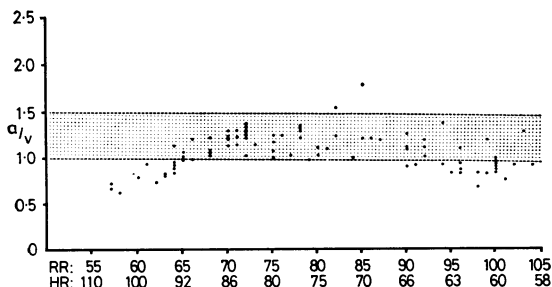


Fig. 8 The "a/v" ratio on the jugular venous tracings on the ordinate, in relation to the RR interval or heart rate on the abscissa. The shaded area is that inside which the "a/v" ratio can be considered normal, the area below is that where the "a/v" ratio is < 1 , that is where the ratio would generally be regarded as diagnostic of atrial septal defect. The points represent 87 "a/v" ratios measured in the same patient during several consecutive recordings in expiratory apnoea. The extreme limits of the "a/v" ratios in this patient are shown in Fig. 3 and are joined by an interrupted line (see text for explanation).

is of the same type as that of normal subjects and is explained by the same physiological mechanisms.

On the other hand, the size of the shunt does not appear to influence the distribution of the "a" waves according to their amplitude in relation to those of the "v" waves, as is shown in Fig. 6. It seems reasonable to expect that cases of atrial septal defect with a large shunt would have an inversion of the "a/v" ratio and, conversely, in those cases of atrial septal defect with a low output, but this is not the case. Some patients with atrial septal defect with a pulmonary output to systemic ratio of more than 2 show larger type 2 "a" waves, larger than the "v" waves and vice versa. However, the mean pulmonary to systemic output ratio showed some correlation with the "a/v" ratio. The mean output ratio was 2.33 when this ratio was below 1, 2.22 when it lay between 1 and 1.5, and 1.92 when it was above 1.5. It, therefore, seems that when the output ratio decreases, the amplitude of the "a" waves exceeds that of the "v" waves and vice versa, though this correlation is not statistically significant.

We conclude that the presence of an atrial septal defect, even with an important shunt does not prevent the height of the "a" wave from being

related to the heart rate as in normal subjects, a fact that has to be taken into consideration in diagnosing atrial septal defect.

Conclusion

The shape of the jugular venous pulse tracing in normal subjects and in patients with an atrial septal defect should be interpreted with caution as the height of the "a" wave varies according to the length of the preceding RR interval, that is the heart rate. For heart rates of 65 to 90 (in this study, 68 to 88 for normal subjects and 62 to 86 for atrial septal defect), the height of the "a" wave is often artificially increased. In normal subjects this could lead to the erroneous conclusion that the right heart pressures are raised. Conversely, in patients with atrial septal defect, this diagnosis could be wrongly dismissed. At a heart rate of below 65 and above 90, the diagnosis of atrial septal defect may be suspected erroneously in a normal subject because the height of the "a" wave could be artificially small as compared with the "v" wave.

For practical purposes the diagnosis of atrial septal defect based on phonomecanocardiographic data should not be automatically dismissed when the "a" wave is larger than the "v" wave, as this can occur in patients with atrial septal defect when the heart rate is between 65 and 90, and it should not automatically be made when the "a" wave is smaller than the "v" wave, for this can happen in normal subjects when the heart rate is either fast or slow.

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